FERROELECTRIC CATHODE MEASUREMENTS

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Abstract

We have recently initiated an investigation of electron emission from ferroelectric cathodes. Our experimental apparatus consisted of an electron diode and a 250 kV, 12 ohm, 70 ns pulsed high voltage power source. A planar triode modulator driven by a synthesized waveform generator initiates the polarization inversion and allows inversion pulse tailoring. Our initial measurements indicate that emission current densities above the Child-Langmuir Space Charge Limit, J_{CL}, are possible. We explain this effect to be based on a non-zero initial energy of the emitted electrons. We also determined that this effect is strongly coupled to relative timing between the inversion pulse and application of the main anode-cathode pulse. We also have initiated brightness measurements of the emitted beam and estimate a preliminary lower bound to be on the order of 10^9 A/m^2-rad^2 for currents close to J_{CL} and factor of two less at currents over $4J_{CL}$. We describe our apparatus and preliminary measurements.

Introduction

New research into fast-switching, ferroelectric emitters promises to dramatically influence the state-of-the-art in pulsed electron device technology. This new class of electron emitter technology has shown extremely high current densities (of order 1 kA-cm^{-2}) and high brightness (10^{10} A-m^2-rad^2) [1,2]. The fact that these emitters can be operated at non-UHV pressures, do not require elevated temperatures or a pulsed laser system, make them a very attractive alternative to conventional cathode technology.

The emission from a ferroelectric is believed to result from the expulsion of charge from the surface and sub-surface layers [1,3]. This effect occurs upon switching the internal polarization by a fast voltage pulse. Typical durations of the emitted beam, in a Zirconium based material, can be of order 200 ns [4]. As the bound charge is quite high, 0.01 - 0.1 mC-cm^{-2}, the resultant electric fields impart significant energy to the emitted electrons. This latter phenomenon has been verified by direct measurement [5] and explains measured current densities in excess of those predicted by the Child-Langmuir space charge limit for electrons with zero initial kinetic energy [6].

One of our motivations for pursuing ferroelectric emitter technology is upgrading the cathode brightness of the high power, pulsed accelerators at the Lawrence Livermore National Laboratory. The Advanced Test Accelerator or ATA (a 50 MeV, 10 kA electron accelerator) [7] and the Flash X-Ray Radiography Accelerator or FXR (a 20 MeV, 4 kA electron accelerator) [8] utilize velvet cathodes for electron production. Although simple, brightness is typically an order of magnitude below that of a high brightness dispenser cathode used on the Experimental Test Accelerator II (a 7.5 MeV, 2.5 kA electron accelerator) [9]. To implement a dispenser cathode on either accelerator, however, would require major upgrades to the injector. In addition, there are applications where gating the electron beam is required. Again, significant modifications to the injector would be required in these applications.

Recent ferroelectric emitter data taken at 4 A-cm^{-2}, 15 A total, showed a brightness of order 10^{10} A-m^{-2}-rad^{-2} (RMS). This result is shown comparatively in Figure 1. The experiment used a 1-2 kV inversion pulse with a variable DC power supply across the anode-cathode (A-K) gap [2], i. e., emission was controlled by the inversion pulse. This data was taken at an A-K potential of 10 kV.

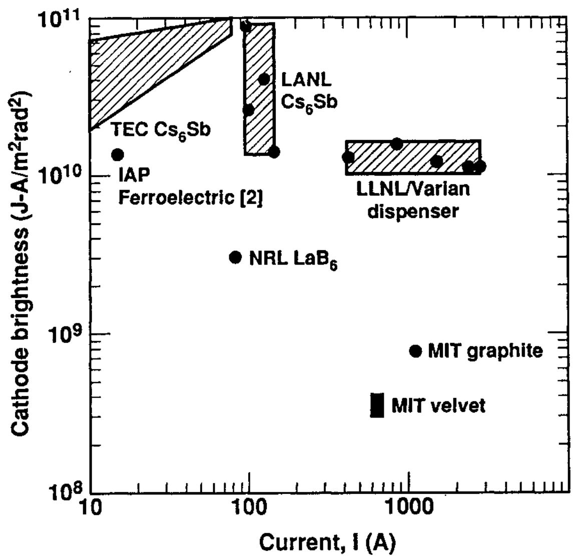

Fig. 1 - Cathode brightness versus current for various cathodes [10].

It is the eventual purpose of our effort to determine if a similar brightness is attainable for kiloampere electron beams. Further, as the emission appears to be dependent on the inversion pulse, we are also trying to determine to what extent the emission can be controlled by the inversion pulse. We report on our apparatus and preliminary measurements.

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Apparatus

The cathode test stand is shown schematically in Figure 2. This apparatus was previously used to measure brightness of osmium coated dispenser cathodes, but was modified to allow exploration of ferroelectric emitters [10].

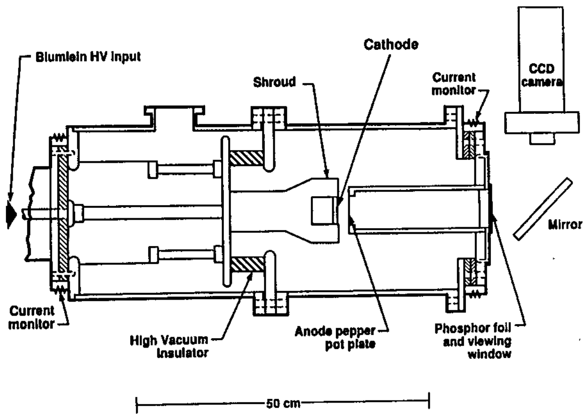

Fig. 2 - Cathode test stand schematic.

A pre-poled, 1 mm thick x 5.1 cm diameter Lead Titanate-Zirconate Piezo Ceramic (LTZ-2) [11] was placed behind a highly transparent grid. The emission side was optically polished; the grid was a square mesh composed of 0.025 mm diameter tungsten wires spaced approximately 0.75 mm on centers. Sample orientation was such that the bound positive charge (negative screening charge) was positioned toward the A-K gap. All but a 3 cm diameter central area of the sample was apertured. The grid-emitter assembly was recessed into the cathode shroud approximately 0.4 cm; the distance from the emitter surface to the anode was approximately 1.8 cm. A copper plate mask, 0.16 cm thick, served as the anode. The entire vacuum system and housing was fabricated from stainless steel; ceramics are used as insulators. Turbo-molecular pumps were used throughout. Base pressures in the 10^{-7} T range were easily achieved and maintained.

Main current was measured by resistive current monitors; A-K potential was measured by a capacitive probe calibrated by a standard resistive probe. Data was recorded with fast analog oscilloscopes.

Core brightness measurements were attempted with a single 100 µ hole aperture and fast phosphor ZnO(Ga). A mask consisting of nine 360 µ holes placed in an "X" pattern was later used. Charging was eliminated with a conductive film placed over the phosphor substrate. Drift distance from the anode mask to the phosphor was 24.5 cm. Microchannel plate intensified, CCD gated cameras, allowed observation of the phosphor image. Gate width used was 40 ns.

The polarization inversion pulse was coupled to the back plane of the ferroelectric emitter via a short length of 10 ohm, coaxial cable. The modulator system was at ground potential while the ferroelectric assembly and cathode stalk were elevated to the accelerating potential. The anode was maintained essentially at ground potential through the resistive current monitor. A stack of ferrite material placed along the 10 ohm coaxial cable provided the isolation impedance from the cathode stalk to ground. In these initial measurements, the system is mismatched so that ferrite reset was provided by the arrival of the first positive reflection; electron current was then initiated at the following reversed polarity pulse.

A polarization inversion pulse was supplied by a set of 32 planar triodes in parallel (Figure 3) [12]. A total current of approximately 0.5 kA at a maximum voltage of 20 kV could be obtained by discharging a 0.05 µF capacitor connected to the ferroelectric backplane via the 10 ohm coaxial cable. The bandwidth of the system was approximately 50 MHz.

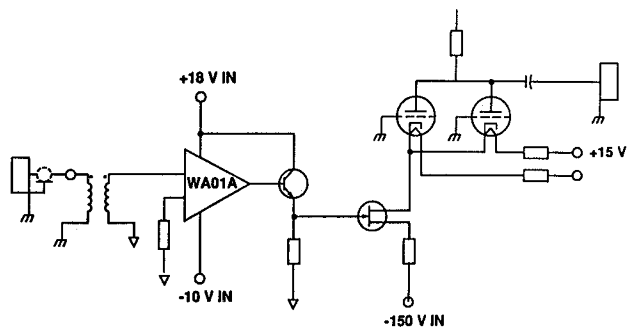

Fig. 3 - Inversion pulse modulator. Sixteen parallel units provide the polarization pulse.

The high voltage pulsed power was supplied by a water filled blumlein. For double pulse capability, we used a magnetically delayed low pressure switch (MDLPS) [13]; double pulses as closely spaced as 50 µs were possible. The system was capable of 5 Hz continuous repetition rate. The blumlein and power supply system were capable of output pulses on the order of 250 kV into 12 ohm.

Experimental Results

Emission from the ferroelectric emitter was achieved with a negative 2-2.4 kV square pulse, 100 ns in length. Approximately 20,000 shots were placed on the ferroelectric emitter at 1 pps with no discernable degradation in the emission characteristics. A-K potential was varied from approximately 15 to 60 kV. Peak currents, J_O, of approximately 150 A were achieved during these initial measurements. As was generally observed, the measured currents were unipolar, consistent with electron flow, and above the Child-Langmuir limit, J_{CL}, for electrons with zero initial kinetic energy.

During initiation of the inversion processes, we characteristically observed multiple discharges between the wire mesh and the ferroelectric emitter. Never-the-less, unipolar current flow is generally observed in the main A-K gap. We also correlated the timing of these discharges with the onset of electron current. In general, we observed discharge initiation upon application of the inversion pulse. Strong electron emission did not occur until several hundred nano-seconds later, however.

To optimize the emission, timing between the inversion pulse and the main A-K pulse was varied (Figure 4). For a fixed A-K potential of 25 kV, the emitted current varied from approximately $0.5J_{CL}$ to $2.8J_{CL}$ over this timing variation. The optimum timing varied sharply about the peak showing a 25% decrease in the emission current for a timing variation of +/-20 ns from the optimum.

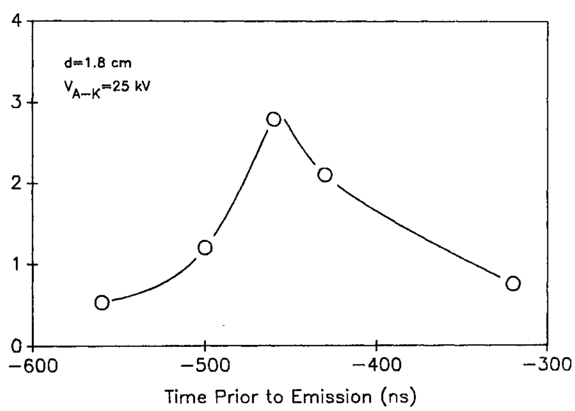

Fig. 4 - Electron current as a function of the timing between polarization inversion pulse and beginning of emission at t=0.

The emitted current from the ferroelectric was measured as a function of the applied A-K potential (Figure 5). In this data, the A-K potential was varied from 16 kV to 41 kV; the emitted current varied from 32 A to 85 A. A significant amount of scatter was present in the data and consistent with that previously measured by others [4]. The data also indicated that the emitted current exceeded J_{CL}. The largest ratio of J_o/J_{CL} occurred at low energies, on average, with much decreased ratios at increased energies.

Initial brightness measurements were attempted with both the single aperture and multi-aperture masks. A-K potential and polarization inversion pulse to the applied A-K potential timing were varied. The inversion pulse potential for this data was 2.4 kV. Data was taken at A-K potentials of 11 kV and 21 kV. Peak gap current varied from 6 A (0.9 J_{CL}) at 11 kV to 42 A (4.7 J_{CL}) at 21 kV.

Brightness measurements with the single aperture mask were unsuccessful. Upon installing the multi-aperture mask, we were able to observe distortion of the mask pattern on the phosphor. Further, the mask image and the intensity of the image of the

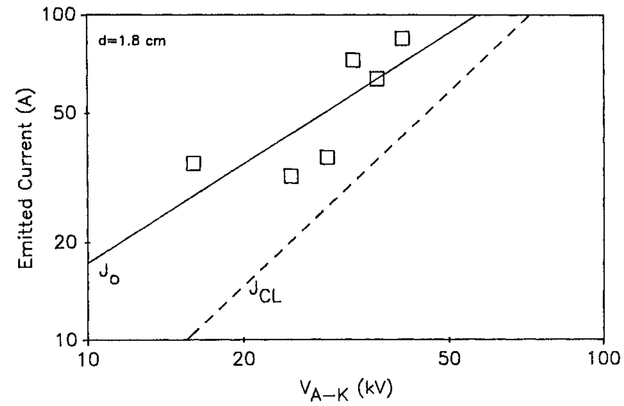

Fig. 5 - V-I characteristics of A-K gap.

beamlets at the phosphor were inconsistent from shot-to-shot at the lower A-K potential.

From the expansion of the beamlets, and inferring the space-charge expansion by aperture hole size and current density at the cathode surface, we estimated the lower bound of the beam brightness. As in similar measurements [10], we estimated this lower bound at 10^9 A/m^2-rad^2 at current densities below $1.7J_{CL}$; at a current density of $4.7J_{CL}$ we estimated the lower bound to be of order 5 x 10^8 A/m^2-rad^2.

Summary

We have begun initial experiments on ferroelectric emitters. As with previous researchers, we observed emitted currents greater than the Child-Langmuir space charge currents for electrons emitted with zero initial energy. A plasma discharge was observed on the ferroelectric surface; gap closure charateristic of a cathode plasma was not observed. We estimate a preliminary brightness of order 10^9 A/m^2-rad^2. We will be modifying the grid structure on the ferroelectric surface, install improved emittance diagnostics and make additional measurements.

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